

Photometric Redshifts in the CFDF

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Abstract. The Canada–France Deep Fields (CFDF) is a large, deep, multi-colour imaging survey undertaken primarily at CFHT. It is about 10 times fainter than the CFRS (Lilly et al 1995a) and contains over 100 times as many galaxies. With three common fields, CFDF redshifts will be estimated photometrically using the CFRS spectroscopic catalogue as a training set. The project will yield large numbers of galaxies and will extend many of the CFRS results to higher redshifts and fainter flux levels.

1. Introduction

Photometric redshifts are increasingly being used for science that previously required expensive spectroscopic redshifts. The Canada–France Deep Fields (CFDF), a collaboration with LeFèvre and his Marseille group, is a large, deep multi-colour imaging survey covering over 1 deg^2 . Photometric redshifts for of order 50,000 galaxies in the CFDF will provide the means to address key issues in galaxy formation and evolution. The large areal coverage and simultaneous depth of the CFDF will enable a measurement of the bright end of the luminosity function (LF) (describing rare, extremely luminous objects) to $z > 3$, as well as an extension of the faint end of the LF (ubiquitous faint objects) a factor of 10 deeper than previous work (Lilly et al 1995b) for $z \leq 1$. The galaxy–galaxy correlation function will be measured in the CFDF to $z \sim 1$ on scales of order $10h^{-1} \text{ Mpc}$, extending into the quasi-linear regime.

2. Observations

The CFDF, undertaken on CFHT and NOAO facilities, is a deep, multi-colour imaging survey that covers over 1 deg^2 . Four $30' \times 30'$ fields were imaged in $UBVI$ to nominal 5σ ($3''$) sensitivities of $U_{AB} = 26.00$, $B_{AB} = 25.75$, $V_{AB} = 25.50$, and $I_{AB} = 25.00$. The image quality is excellent, ranging from about $0.6''$ in I to about $1.0''$ in B . Several problems unique to CFHT's UH8k camera (Metzger et al 1995) slowed the data reduction, however the pipeline is now in place. The reduction is about 50% complete and should be finished in a few months.

In order to obtain contiguous optical wavelength coverage (out to 1 micron), the original *UBVI* survey is currently being supplemented with *R*- and *Z*- band data taken with the new CFH 12k CCD mosaic camera at CFHT. Some of this data is already in hand. It has been noted by several authors (e.g. Connolly et al 1997, Fernandez-Soto et al 1999; see Yee 1998 for a review) that additional NIR imaging is required to remove intrinsic degeneracies that exist between distinct galaxy types at different redshifts. KPNO time has been allocated for infrared (*K'*) imaging of part of the CFDF fields with IRIM. The necessity of obtaining data at wavelengths longer than the *I*-band was explicitly demonstrated in the detailed Monte Carlo simulations that are described in the next section. The inclusion of one IR band renders photometric redshifts immune to catastrophic errors and reduces the dispersion at all redshifts.

3. Photometric Redshifts

Extensive Monte Carlo simulations were performed in order to test the feasibility of photometric redshift estimation in the CFDF. Repeated interpolation between the Coleman, Wu, and Weedman (1980, hereafter CWW) spectral energy distributions (SEDs) for E, Sbc, Scd, and Irr galaxies resulted in 13 distinct template SEDs. The CWW SEDs do not extend blueward of 1400 Å. While strong Ly α emission aids both in the detection of faint galaxies and in estimation of their redshifts, it is often weak or absent due to severe dust obscuration. In an effort to remain as conservative as possible, the CWW SEDs were extrapolated to 1216 Å and were set to zero blueward. No modelling of the line was attempted, and little would be gained by extrapolating the SEDs right to 912 Å. The SEDs were convolved with generic $\Delta\lambda/\lambda \sim 20\%$ filter response curves. To create the target galaxies, these SEDs were then redshifted into the range $0 \leq z \leq 2.6$ at $\Delta z = 0.1$ intervals and random photometric errors consistent with those present in the CFDF were added. A χ^2 fitting algorithm was used to compare the redshifted templates with the target galaxies, with the minimum value of χ^2 corresponding to the best fitting redshift and template. The simulation was run 100 times for each target galaxy (with different random photometric error each time), enabling an estimation of the typical dispersion in the best-fit redshift.

Several speakers at this meeting have pointed out that the use of spectroscopic training sets result in better redshift estimates than the use of templates derived from population synthesis models or measurements of local SEDs (as in these simulations). This is due in part to the difficulty in accounting for galactic evolution, which is naturally present in a spectroscopic catalogue. However, in these simulations no evolutionary *difference* between target and template galaxies was present, therefore the accuracy should be similar to what would be obtained on real galaxies using an empirical training set. In the final analysis the ~ 600 CFRS galaxies with spectroscopic redshifts to $z \leq 1.3$ will be used to train the redshift-finding algorithm.

The top panels of Figure 1 illustrate the results for $I_{AB} = 24$ early- and late-type galaxies with the existing/scheduled *UBVRIZ* data. Aliasing between ($z \sim 0$) ellipticals and ($z \sim 2$) spirals is apparent. This is likely due to the confusion of the Balmer break and the redshifted UV cutoff. Note that between $0.25 \leq z \leq 1.25$ the results are unaffected by this degeneracy and the photometric redshifts

Redshift	Simulated σ_z with <i>UBVRIZ</i>			
Interval	E/S0	Sbc	Scd	Irr
0.25–0.75	0.13	0.09	0.08	0.09
0.75–1.25	0.16	0.15	0.10	0.10
1.25–1.75	0.16	0.17	0.36	0.21
1.75–2.25	0.05	0.42	0.64	0.17

Redshift	Simulated σ_z with <i>UBVRIZK'</i>			
Interval	E/S0	Sbc	Scd	Irr
0.25–0.75	0.07	0.09	0.07	0.08
0.75–1.25	0.05	0.07	0.07	0.08
1.25–1.75	0.04	0.06	0.06	0.10
1.75–2.25	0.03	0.10	0.10	0.17

Table 1. Summary of simulated redshift dispersions for faint $I_{AB} = 24$ galaxies imaged in *UBVRIZ* and *UBVRIZK'* in Monte Carlo simulations. The dispersions are averaged over $\Delta z = 0.5$ redshift bins. With the optical data, the redshifts are good to $z \leq 1.25$, whereas the addition of K' allows accurate prediction at all redshifts

for these faint $I_{AB} = 24$ galaxies have mean dispersions of about $\sigma_z \leq 0.16$ (see Table 1). The insets show the photometric redshift distribution obtained in the 100 trials at $z = 1$ and $z = 2$. The $z = 1$ redshift distribution is basically free of catastrophic errors in the redshift estimate, whereas the above-mentioned aliasing produces a strongly non-gaussian redshift distribution for late-type galaxies at $z \sim 2$. A similar distribution exists for $z \sim 0$ ellipticals. Catastrophic errors would clearly make an analysis impossible at these redshifts.

The addition of K' -data (bottom panels) removes all degeneracies and allows more accurate photometric redshifts to be estimated at $0 \leq z \leq 2.6$ and probably to higher redshifts due to the presence of the Lyman break. There are no catastrophic errors at $z = 1$ or $z = 2$; the redshift distributions are almost delta functions centered on the correct redshift.

Figure 2 shows the redshift dispersion as a function of redshift for each of the original CWW galaxy types for the optical and optical+NIR filter sets. The degeneracy between $z \sim 0$ ellipticals and $z \sim 2$ spirals is clearly seen for the *UBVRIZ* estimates, but disappears when K' is added. (The error spike in $z \sim 1.5$ late-type galaxies is an artifact caused by the inclusion of negative redshift template ellipticals used to obtain gaussian errors at $z = 0$.) At $0.2 \leq z \leq 1.2$, the mean redshift dispersion for all types of $I_{AB} = 24$ galaxies is $\bar{\sigma}_z \leq 0.16$, with *no contamination from higher or lower redshift objects*. Thus analyses performed at $z \sim 1$ should be immune to catastrophic redshift errors. Note that with the addition of K' data, the mean dispersion drops to $\bar{\sigma}_z \leq 0.1$ for all galaxies to at least $z \sim 2$, with *no catastrophic errors at any redshifts*. The salient features of this Figure are summarized in Table 1.

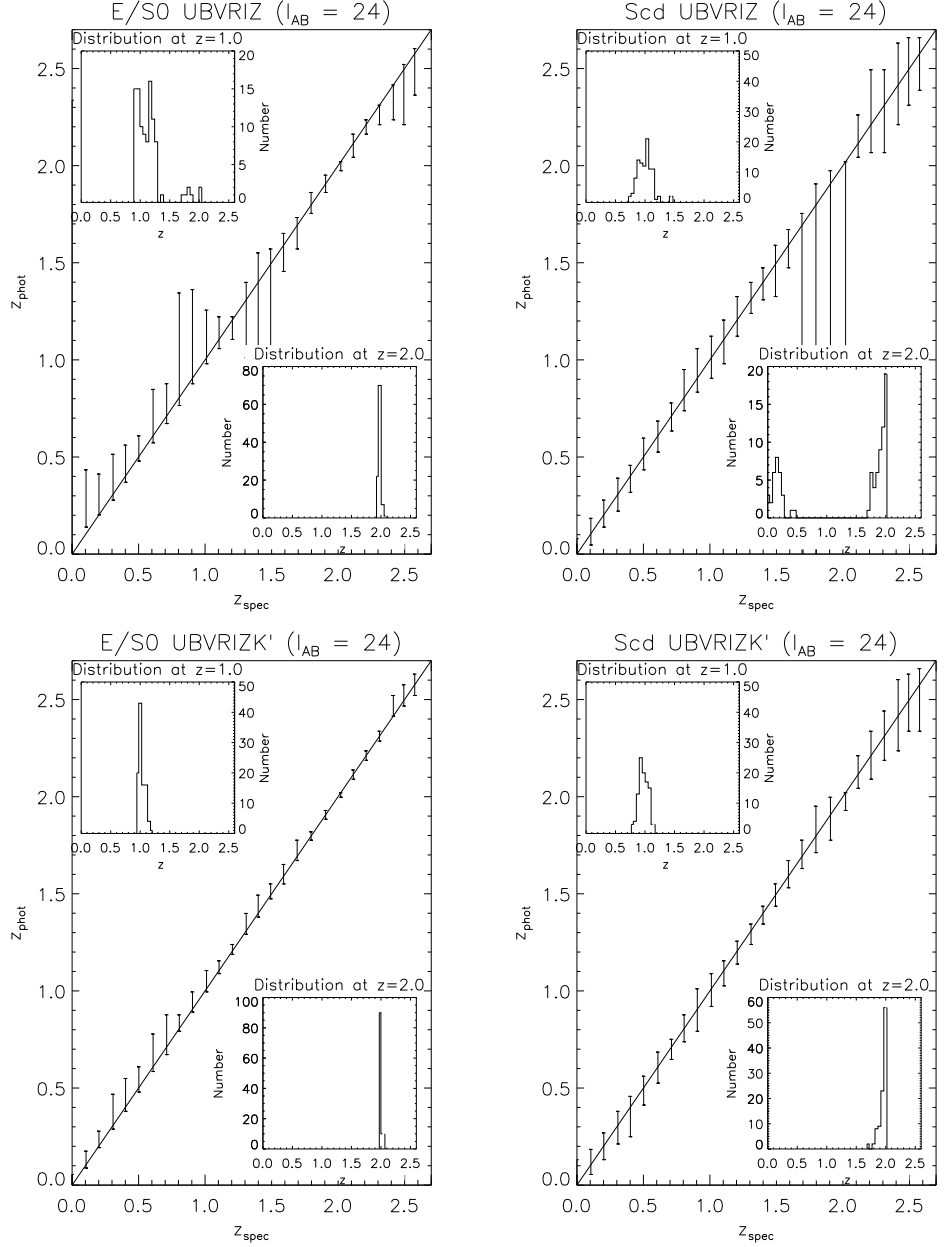


Figure 1. The top panels plot z_{phot} vs. z_{spec} obtained for early- and late-type $I_{\text{AB}} = 24$ model galaxies for which *UBVRIZ* data (at the nominal sensitivities of the CFDF) are available. The full error bars span the central 2/3 of the best-fit redshifts. The insets of these panels show the complete redshift distributions at $z = 1$ (essentially gaussian) and $z = 2$ (clearly demonstrating the occurrence of catastrophic errors). The bottom panels show the results obtained when *K'* data is added. The error bars are reduced and the catastrophic errors (insets) are eliminated at all redshifts.

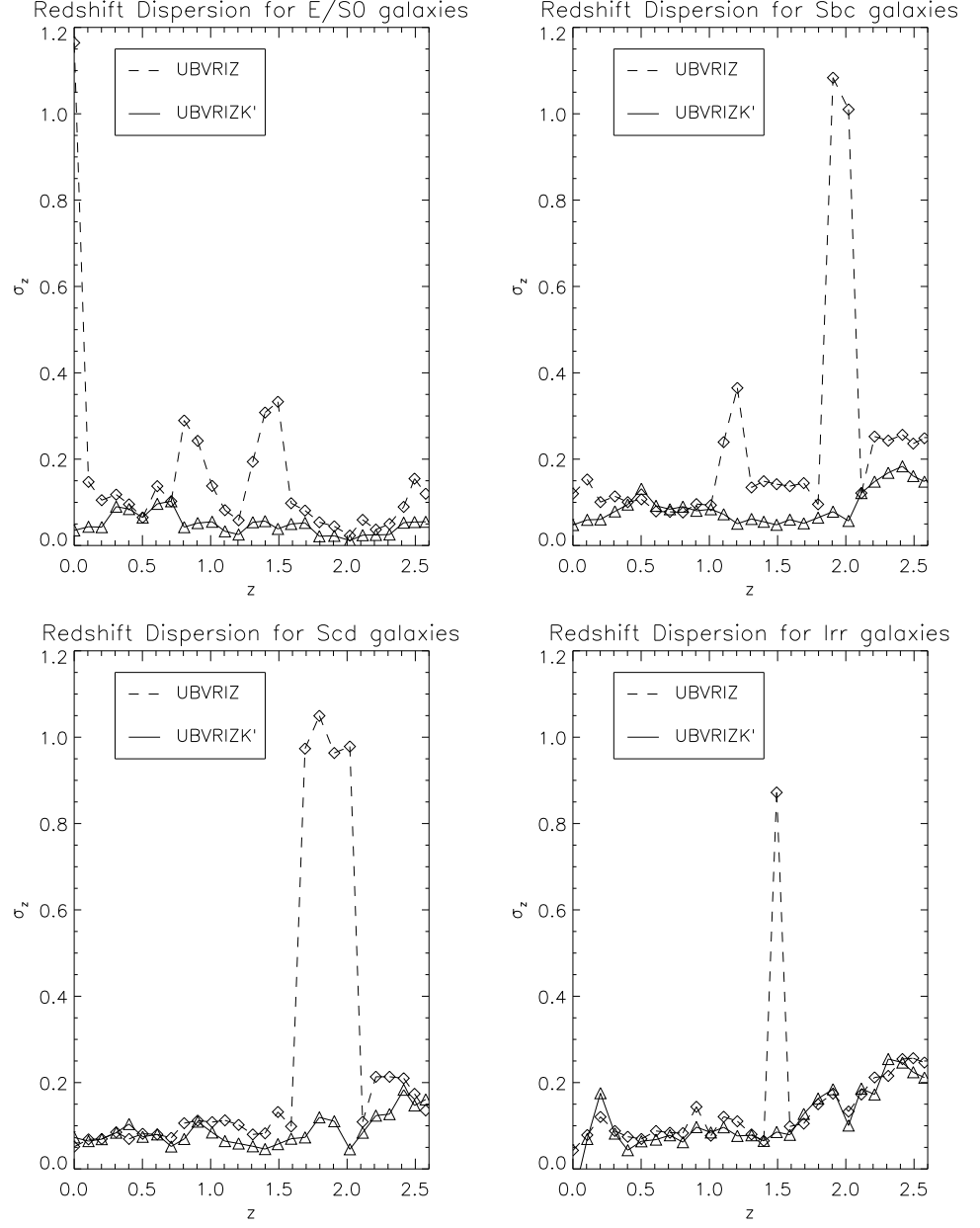


Figure 2. Redshift Dispersion vs. Redshift is plotted for the CWW galaxy types. Between $0.2 \leq z \leq 1.2$, a mean dispersion of $\bar{\sigma}_z \leq 0.16$ is obtained for all galaxies (see summary in Table 1), with no contamination from other redshift regimes. The aliasing of high- z spirals and low- z ellipticals is readily apparent, but will not affect analyses at $z \sim 1$. The addition of K' -data removes this degeneracy and allows accurate ($\bar{\sigma}_z \leq 0.1$) photometric redshifts for all galaxy types to at least $z \sim 2$ with no catastrophic errors over the entire redshift range $0 \leq z \leq 2.6$.

4. Conclusions

The CFDF is a large, deep, *UBVRIZK'* imaging survey covering over 1 deg^2 and containing $\sim 100,000$ galaxies to $I_{AB} = 25$. The science goals of the CFDF include measurements of the luminosity and correlation functions of galaxies to $z \sim 1$. As accurate photometric redshifts are required for these analyses, detailed Monte Carlo simulations were conducted to characterize the expected redshift errors. These simulations indicate that for faint $I_{AB} = 24$ galaxies, redshift dispersions of $\bar{\sigma}_z \leq 0.16$ can be expected in the range $0.2 \leq z \leq 1.2$ for all galaxies imaged in *UBVRIZ*, with no significant occurrence of catastrophic errors in redshift estimation. For the data additionally imaged in the near infrared (*K'*), the dispersion drops to $\bar{\sigma}_z \leq 0.1$ over the range $0 \leq z \leq 2$ ($\bar{\sigma}_z \leq 0.08$ at $z \sim 1$) with no catastrophic errors at these or higher redshifts. It is therefore expected that the redshift accuracy in the CFDF is sufficient to allow its science goals to be achieved.

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References

- Coleman, G. D., Wu, C., & Weedman, D. W. 1980, *ApJS*, 43, 393 (CWW)
Connolly, A. J., Szalay, A. S., Dickinson, M., SubbaRao, M. U., & Brunner, R. J. 1997, *ApJ*, 486, L11
Fernandez-Soto, A., Lanzetta, K. M., & Yahil A. 1999, *ApJ*, 513, 34
Lilly, S. J., Le Fèvre, O., Crampton, D., Hammer, F., & Tresse, L. 1995a, *ApJ*, 455, 50
Lilly, S. J., Tresse, L., Hammer, F., Crampton, D., & Le Fèvre, O. 1995b, *ApJ*, 455, 108
Metzger, M. R., Luppino, G. A., & Miyazaki, S. 1995, AAS Meeting, 187 #73.05
Yee 1998, To appear in the proceedings of the Xth Rencontres des Blois: *The Birth of Galaxies* (astro-ph/9809347)